Occurrence Statistics of Cold Convecting Ions in the Earth's Dayside Outer Magnetosphere – Implication of Global Convection

S.-H. Chen

Universities Space Research Association, Seabrook, Maryland, USA

T. E. Moore

Interplanetary Physics Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

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Abstract

We have surveyed four years of Polar TIDE data between January 1, 2000 and June 30, 2003 when Polar apogee paths were in the dayside outer magnetosphere (r > 5 R_E) to study the cold (~1 eV) convecting (~30 – 300 km s^{-1}) ions (CCI). We have found a dawn-dusk asymmetry on the occurrence of CCI. The occurrence rate was significantly higher in the dusk side. Particularly at 13-16 hours of local times near the magnetopause the chances to encounter CCI were >50%, compared with <30% at the dawn side. The CCI events could be related to the plasmaspheric drainage plumes observed by IMAGE spacecraft or geosynchronous orbiters. The repetition of the plasmaspheric loss, convection, magnetopause reconnection and plasmaspheric replenish processes prescribes a driver for the dynamo process in the global magnetospheric convection. The similar dawn-dusk asymmetry persists in both subsets grouped by the signs of IMF By and Bz, respectively.

Introduction

The dynamics of the interaction of the hot solar wind and the cold Earth's ionospheric plasmas locally at the magnetopause has recently been found crucial in magnetospheric convection at a global scale [*Chen and Moore*, 2004 and references therein]. Recent observations of sunward convecting plasmaspheric drainage plumes – originally ionospheric plasma, by several remote sensing instruments on IMAGE spacecraft depicted a large scale dynamics of the cold ionospheric plasma beyond the geosynchronous orbit at the dusk side [*Sandel, et al.,* 2003; *Goldstein, et al.,* 2003*a* and references therein]. The plasma characteristics at the magnetopause and at the geosynchronous orbit were found to be similar. Incorporated with data from solar wind monitors, geosynchronous orbiters, and ground geomagnetic indices, many studies have found that the plasmaspheric drainage plumes were correlated with upstream solar wind conditions and geomagnetic activities [*Carpenter, et al.,* 1992; *Horwitz, et al*., 1990; *Moldwin, et al.,* 2003; *Spasojević, et al.,* 2003; *Goldstein, et al.,* 2004; *Moldwin, et al.*, 2004 and references therein]. Similar correlations were also found in the cold ions at the magnetopause [*Chen and Moore*, 2004]. The preliminary study of magnetopause cold ions by Chandler et al. [2003] have shown more cold ions present at the dusk side magnetopause than at the dawn side. Could the plasmaspheric drainage plumes at the geosynchronous distance be related to the cold ionospheric ions found at the magnetopause and take part in an even larger scale of magnetospheric convection?

Despite of the profound discovery, the prevalence of the cold ionospheric ions in the outer magnetosphere has not yet been studied because of the limited number of samples that were confined to the magnetopause [*Chandler, et al.,* 2003; *Chen and Moore*, 2004]. To expand the study to include a larger database of the similar events with more pertinent spatial coverage, we have surveyed four years of Polar TIDE data [*Moore, et al*., 1995] between 2000 and 2003 when the apogee paths were in the dayside outer magnetosphere between 6 and 18-hour local times and ±60° latitudes. Although Polar was in a polar orbit that traveled mostly out of the equatorial plane, the swings of the apogees of the highly elliptical orbits 35° above and below the equatorial plane over the four-year period enabled us to collect measurements in the equatorial plane at distances inside the apogees as the orbits intersected at distances closer. Our new data collection covers the dayside magnetosphere between the apogees (~9 R_E) and distances just inside the geosynchronous orbit (~5 R_E). Although short in distances to the averaged magnetopause position (~10 R_E), it still contains a significant number of orbits near the magnetopause as the highly variable solar wind pressure could easily push the magnetopause inside the apogees. With the data set that covered the space between the magnetopause and the geosynchronous orbit, we are able to look into the insight of the plasmaspheric plumes at distances beyond the geosynchronous orbit and their connection to the cold ionospheric ions found at the magnetopause. In this paper, we will carry out the statistical analysis on the spatial occurrence of the cold convecting ions (CCI) and its relationship to the orientation of IMF.

Analysis

We have surveyed four years of Polar TIDE data for cold convecting ions (CCI) [*Chen and Moore*, 2004] when the spacecraft was at the dayside outer magnetosphere. During the periods between January 1 and June 30 of each year from 2000 to 2003, Polar apogee paths ($r > 5\ R_E$) covered a wide range of local times between 6 to 18 hours and magnetic latitudes of ±60°. Figure 1 shows the orbital projections in X-Y and Y-Z GSM planes. Figure 2 shows the contours of the numbers of equatorial crossings within ±37.5° above or below X-Y GSM plane in 1 R_E by 1-hour local time bins. The number of crossings in each bin represents the summation of the numbers of crossings of five 15° latitudinal bins (one at the equator ±7.5, two above and two below). It was only counted once per orbit when the spacecraft was present in each bin. The summation of the latitudinal bins is to increase the chances of observing CCI that might be confined to a plane deviated from the GSM equator, e.g., the dipole magnetic coordinate, and most importantly to minimize the orbital biases (see discussion below). By browsing TIDE ion spectrograms of differential fluxes versus energy and spin-angle overlaid with magnetic field orientation indicators, we searched for CCI intervals that had the following characteristics: their energy spreadings were relatively narrow (~ 1 eV), their peak energies were well above the spacecraft potential (few eV or few tens of km s^{-1}) and below the instrument upper energy threshold (~400 eV or ~300 km s^{-1}) and their flowing directions were perpendicular, but not merely sunward, to the background magnetic field. The spacecraft velocities were negligible (<5 km s^{-1}) at distances beyond 5 R_E compared with the velocity shifts due to the spacecraft potential. We logged the start and stop times when these ions were present continuously or intermittently but prevailed. The durations of the intervals could be as short as 10 min and as long as few hours. We have collected a total of 398 intervals with the presence of CCI among more than 12,000 hours of apogee paths surveyed.

We incorporated solar wind data from ACE spacecraft at the L1 point with the CCI intervals and corrected the time lags based on the simple convection model, i.e., $X \times V_X$. Figure 3 shows the histograms of solar wind dynamic pressure and IMF components. The averaged solar wind dynamic pressure is ~1.8 nPa (black) and the averaged IMF Bz (red) is near zero. The averaged IMF Bx (green dashes) and By (blue) are slightly shifted to the negative and positive side, respectively, with more significant deviations from their averages. Our collection of CCI events represents a data set that has a typical solar wind dynamic pressure variation and a wide range of IMF orientations with relatively moderate biases mainly in the IMF Bx and By.

Figure 4*a* and 4*b* show the orbital traces of the 398 CCI intervals in GSM coordinate. Significantly more CCI intervals occur at the dusk side than at the dawn side. By comparing with the orbital traces for the whole data set in Figure 1 and Figure 2, there were a good number of equatorial crossings in both the dawn and dusk side of the magnetosphere. This assures us in the efforts to improve the statistics and to minimize the orbital biases while analyzing orbits in the GSM coordinate: spring seasonal bias (January 1 to June 30) toward +Z at dusk (upper-right quadrant of Figure 1*b*) and - Z at dawn (lower-left quadrant), and epoch bias toward +Z (more apogees above the equatorial plane between 2000 and 2003). With all the efforts applied, the dawn-dusk asymmetry in our CCI collection is proven to be statistically significant. Figure 4*c* shows the orbital traces again in X-Y GSM but after the orbit of each CCI occurrence was normalized and adjusted to the same magnetopause-earth distance at its fixed local time for the averaged solar wind dynamic pressure of 1.8 nPa (Figure 3) in the whole CCI collection (using the magnetopause model of Shue et al. [1997]). It shows the radial spreading of the orbits but as expected the similar asymmetrical pattern persists.

Figure 4*d* shows the contours of the occurrence rate of CCI relative to the whole data set (Figure 2). The contour levels are percentages in logarithmic scale. The method of counting CCI orbital presence is the same as the one for the whole data set described earlier in the paper. The chances of observing CCI were significantly higher at the dusk side. The occurrence rate of CCI at most locations beyond the geosynchronous orbit (dashed curve) at the dusk side was 10% or higher compared with ~0% at the dawn side. The occurrence rate near the dusk side magnetopause, particularly at 13-16 hours of local times, was >50% compared with only <30% in a relative narrow pre-noon local time sector at the dawn side magnetopause. The occurrence rate at the local time sector of ~9-hour LT was extremely low (<5%). A higher CCI occurrence rate indicates a higher chance to observe dynamically disturbed, either convecting or oscillating, cold ions. Because of the similarities in the spatial distribution and plasma characteristics, the regions of high CCI occurrences in the dusk side could be related to the extension of plasmaspheric drainage plumes at the geosynchronous orbit observed by IMAGE spacecraft and geosynchronous orbiters [*Sandel, et al.,* 2003; *Moldwin, et al.,* 2003; *Goldstein, et al.,* 2004; *Moldwin, et al.,* 2003]. The higher CCI occurrences at distances closer to the magnetopause could also indicate a more dynamic process at the magnetopause boundary than at the geosynchronous orbit.

Figure 5 shows the subsets of dynamic pressure normalized CCI orbital traces grouped by the signs of IMF Bz and By, respectively. The number of CCI occurrences during southward IMF (negative Bz) was slightly higher than that during the northward IMF (positive Bz). This is consistent with the stronger sunward convection or more highly perturbed field lines in the outer magnetosphere during southward IMF when reconnection at the magnetopause is likely. The number of CCI occurrences during positive IMF By (pointing to the dusk side) was slightly higher than that during negative (pointing to the dawn side). Although the asymmetry persists in both groups, there was an orbital bias in our set that Polar spent more time below the equatorial plane at the dawn side and more time above at the dusk side during the apogee paths (Figure 1*b*), the IMF By effect in the relationship between the IMF clock angle and the occurrence of CCI is inconclusive. Besides the solar wind dynamic pressure and the IMF orientation, the controlling factors such as conditions for plasma instabilities at the magnetopause, the gain and loss of plasmaspheric ions, geomagnetic activities, etc., are also important but yet to be pursued further.

Conclusion

We have found the dawn-dusk asymmetry of the occurrence of the cold convecting ions (CCI) in the outer magnetosphere. Significantly more CCI events occurred at the dusk side than at the dawn side, consistent with the location of plasmaspheric drainage plumes but further away from the geosynchronous orbit. Particularly at 13-16 hours of local time sector the occurrence rate increases from ~20% at the geosynchronous orbit to 50% or higher near the magnetopause, compared with the best occurrences of ~0% to ~30% in the pre-noon sector at the dawn side. In the local time sector of ~9-hour near the magnetopause, the occurrence rate is extremely low (<5%). A higher CCI occurrence rate indicates a higher chance to observe dynamically disturbed, either convecting or oscillating, cold ions. Because of the spatial distribution and the plasma characteristics, these CCI events could be related to the extension of the plasmaspheric drainage plumes that carrying cold ionospheric ions sunward. The higher CCI occurrence rate at the dusk side magnetopause could setup local plasma conditions that favorable of reconnection [*Chen and Moore*, 2004; *Le, et al*., 2004] and enhance the strength of convection at the dusk side [*Carpenter, et al.,* 1992; *Foster, et al.*, 2002; *Goldstein, et al.,* 2003*b*] and drain more cold ionospheric ions from the plasmasphere, convect sunward, replenish with the cold ions again at the magnetopause boundary, and further increase the rate of reconnection at the magnetopause. The repetition prescribes a driver for the dynamo process in the global magnetospheric convection. The effect of IMF By and Bz on the dawn-dusk asymmetry was insignificant. The similar dawn-dusk asymmetry persists in both subsets grouped by the signs of IMF By and Bz, respectively.

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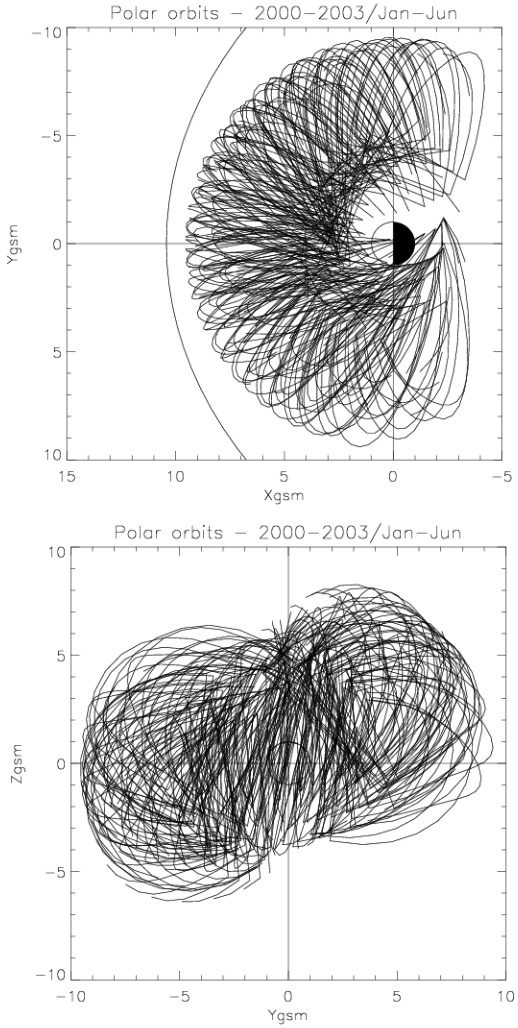

Figure 1. Traces of apogee-half orbits (r > 5 R_E) of Polar spacecraft between January 1 and June 30 of each year from 2000 to 2003 when the cold convecting ions (CCI) were surveyed. To reveal more clearly the density of the orbital distributions, only every five-day of orbits are shown. Plotted in (a) X-Y GSM (b) Y-Z GSM. The model magnetopause of Shue et al. [1997] for the solar wind dynamic pressure of 1.8 nPa and zero IMF is shown.

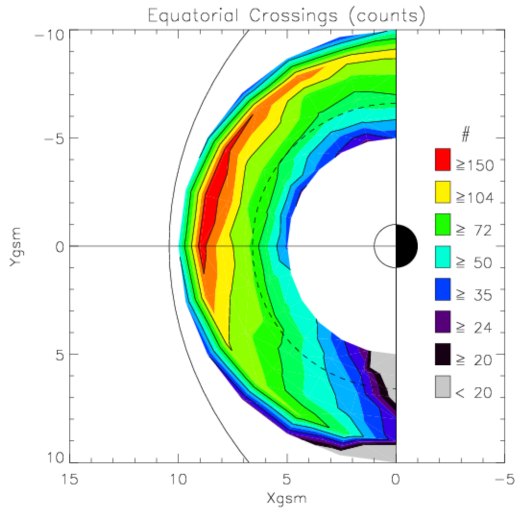

Figure 2. Distribution of the number of equatorial crossings (sum of five 15° latitude bins ±37.5° from Z_{GSM}=0) in 1 R_E x 1 MLT-hour bins over the period surveyed (Figure 1). The dashed curve is the geosynchronous distance of 6.6 R_E. The contour levels are counts in logarithmic scale. The model magnetopause of Shue et al. [1997] for the solar wind dynamic pressure of 1.8 nPa and zero IMF is shown.

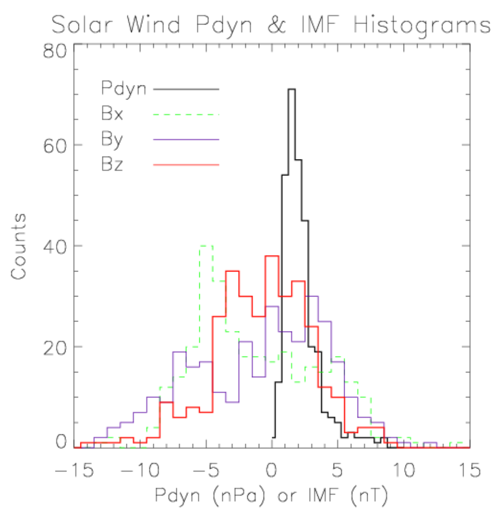

Figure 3. Histograms of solar wind dynamic pressure (black), IMF Bx (green dashes), By (blue), and Bz (red) components in GSM coordinate for cold convecting ions (CCI) events. The total number of CCI events is 398.

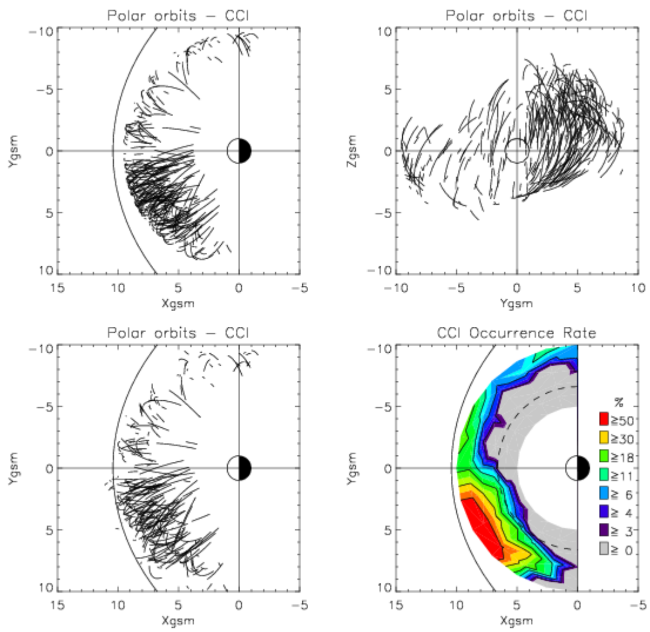

Figure 4. Orbital traces during the intervals when cold convecting ions (CCI) were observed. Plotted in (a) X-Y GSM (b) Y-Z GSM and again (c) X-Y GSM after the radial distances were normalized by the effect of solar wind dynamic pressure [*Shue et al.,* 1997] at 1.8 nPa and zero IMF. (d) Contours of the occurrence rate of CCI events relative to the whole data set surveyed (Figure 2). The dashed curve is the geosynchronous distance of 6.6 R_E. The contour levels are percentages in logarithmic scale. The model magnetopause of Shue et al. [1997] is shown.

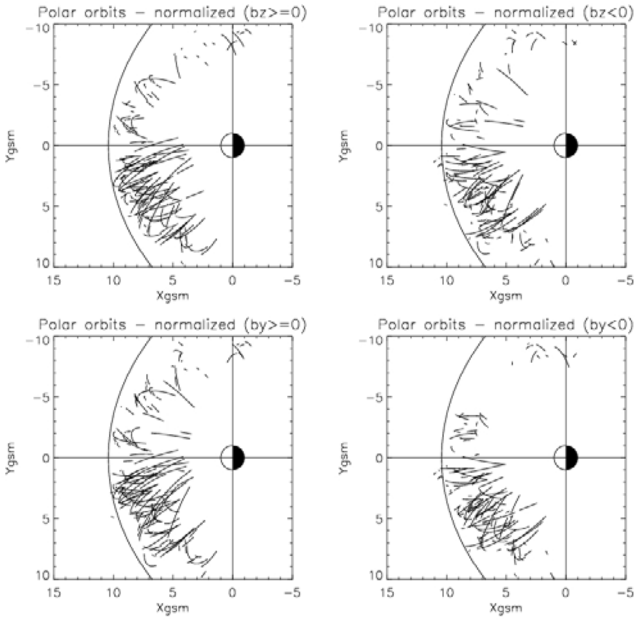

Figure 5. Subsets of solar wind dynamic pressure normalized CCI orbital traces (Figure 4c) grouped by the signs of IMF Bz and By, respectively: (a) Bz ≥ 0, (b) Bz < 0, (c) By ≥ 0, and (d) By < 0.